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JUNE 1961

EXPERIMENTAL STUDY OF MAGNETIC EFFECTS IN STEEL UNDER EXPLOSIVE LOADING

Robert E. Franz

Department of the Army Project No. 503-04-002
Ordnance Management Structure Code No. 5010.11.815

BALLISTIC RESEARCH LABORATORIES

ABERDEEN PROVING GROUND, MARYLAND

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ABSTRACT

A series of experiments have been performed in order to study the magnetic effects of pressure waves propagated in magnetized steel rods. Typical cases are shown for different values of magnetization. Measurements of wave velocity were made and a value of 5.936 ± 0.092 mm/μ sec obtained. Correlation of pressure levels with static tests was found to be poor.

INTRODUCTION

It is known that pressure waves propagated in magnetized steel or iron cause magnetic changes in the material.[1,2,3] This is not unexpected since stress is one of the major factors affecting the magnetic properties of all ferromagnetic materials. Changes in magnetization due to the application of static tension or compression have long been known and measured.[4,5] These changes are affected by several things which are difficult to control, such as the previous magnetic and metallurgical treatment of the material. Divergent data may be found for similar materials due to just such differences[5] so that in any experimental study care must be taken to assure uniformity of the experimental materials. The purpose of the experiments related in this report was to study the changes in magnetic flux in steel rods which underwent explosive loading and to correlate them with the stresses produced by such loading.

EXPERIMENTAL PROCEDURE

The explosive used was 50/50 pentolite cast in 3" long cylinders 1" in diameter. These were placed against annealed 1030 carbon steel cylinders of the same diameter and approximately 16" long. The steel specimens were clamped in a soft iron yoke which had a coil wound on it to provide an m. m. f. for magnetizing the specimen (Figure 1). This gave a comparatively constant flux along the length of the specimen which could be varied from low values to saturation.

Other tests were made with a large solenoid. This made the steel rods an open magnetic circuit with attendant demagnetizing effects at the ends and an appreciable lag in magnetization at rapid rates.[6]

Search coils were placed around the specimen at various distances from the explosive-metal interface. These consisted of 5 turns of No. 22 Formex wire wound on insulation tubing. The axial width of the coils was approximately 1 mm. Flux density measurements were made using a General Electric Company fluxmeter and the coils were subsequently connected to a number of oscilloscopes which were triggered at measured time intervals.

The initial trigger was provided by a pair of insulated wires twisted together and placed at the explosive-metal interface. These shorted as the detonation front passed and a simple electronic circuit started a time delay generator which in turn triggered the oscilloscope sweeping circuits. Oscillograms were taken on Polaroid Lantern Slide Film on which timing marks were placed previous to firing.

RESULTS

Figure 2 shows typical oscillograms obtained in this manner at 10.8 and 22.8 cm. down the rod from the explosive and at different initial flux densities. Positive going signals are caused by a decrease in magnetic flux. An increase in the initial magnetization of the specimen causes an increase in pulse height which then decreases with a further increase in the magnetization. When a critical value is reached (approximately 14 kilogauss) the signals reverse sign showing an increase of flux in the rod. The behavior closely resembles what is called the Villari Reversal.[4] That is, a depression of the magnetization curve of iron by pressure at low initial flux densities and an increase in magnetization at high flux densities with a crossover at around the knee of the magnetization curve (13 14 kilogauss), hence the name Reversal. Figure 3 shows the first voltage peak plotted against initial flux density. In most cases three main pulses are obtained. Their time spacing is approximately constant, being at a frequency of about 200 kilocycles.

Figure 4 shows some oscillograms obtained using the large solenoid. These shots were used to measure the velocity of the pressure wave in the rods. This was found to be 5.936 ± 0.092 mm/μ sec. which is close to the velocity measured ultrasonically at 10 megacycles (5.96 mm/μ sec).

In order to correlate changes in magnetization and pressure levels in the steel that was used, static loading tests were performed and pressure versus change in magnetization measured. This relationship is essentially linear for a given initial flux density and diameter of rod. Figure 5 shows the results of these tests with a 1" diameter rod. Figure 6 shows the results at given initial flux and different diameters.

CONCLUSIONS

It can be seen from the equation for electromagnetic induction that the pressure should be proportional to the integral of the instantaneous voltage induced in the search coil if eddy currents and hysteresis loss are neglected; thus:

$$e = -N\frac{d\Phi}{dt} \times 10^{-8} \text{ volts};$$

$$\frac{\Delta\Phi}{\Delta t} = \frac{k\Delta p}{\Delta t} .$$

Letting $\Delta t \to 0$ and taking limits,

$$\frac{d\Phi}{dt} = k\frac{dp}{dt} ;$$

then

$$e = -Nk\frac{dp}{dt} \times 10^{-8}$$

and

$$p = -\frac{10^8}{kN}\int e\,dt,$$

where Φ = flux in Maxwells

t = time in seconds

N = number of turns on search coil

p = pressure in psi

k = coefficient of pressure in maxwells/psi.

Pressure profiles were calculated by integration of the signals obtained from the search coils. These values of pressure turn out to be extremely low at distances 10.8 cm & 22.8 cm down the rod, reaching a maximum of only 5-6 thousand psi, as compared to values of pressure obtained by pin measurements at the same points. Pin measurements indicate pressures almost 10 times the magnitude of those calculated from magnetic effects. It is interesting to note that the magnetic measurements are consistent within themselves since, at different initial flux densities the pressures deduced are approximately the same. Figure 7 shows the curves obtained with the oscillograms of Figure 2. Figure 8 shows the results from two different diameter rods. It should be pointed out that the details of the calculated pressure-time curves are preserved for different initial flux densities although no explanation of this behavior can be given. The pressures obtained by the magnetic flux method are probably most seriously affected by eddy current losses in the steel, magnetic viscosity effects, and to a lesser degree by hysteresis effects.

Robert E. Franz
ROBERT E. FRANZ

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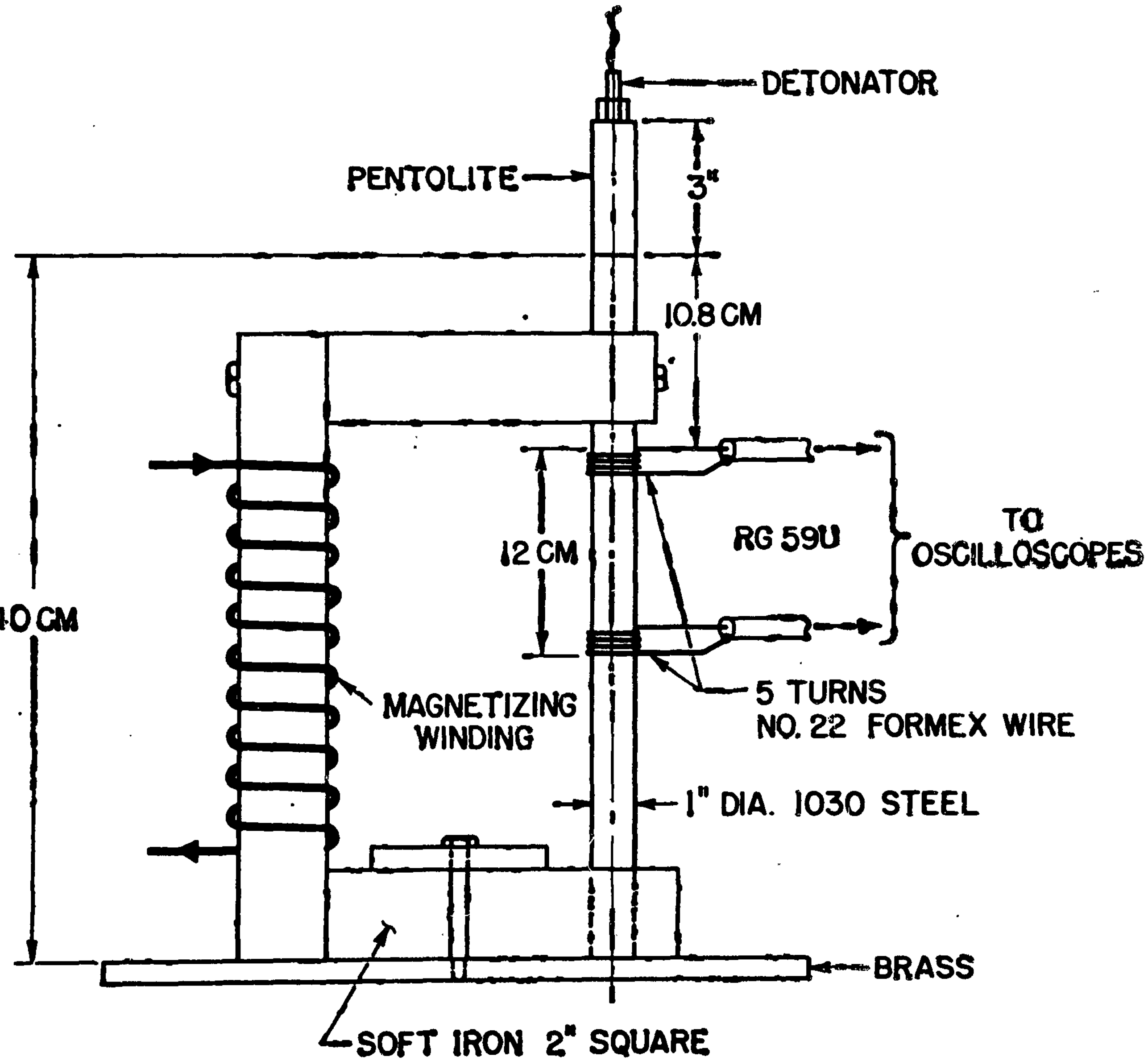
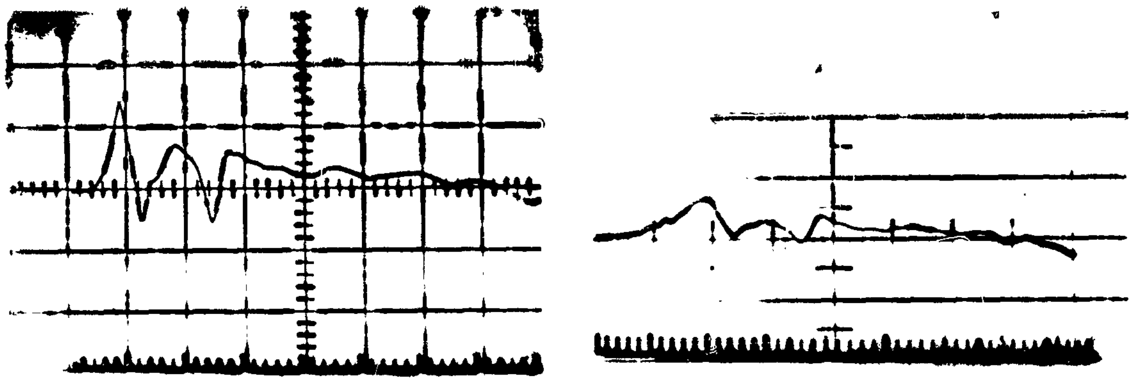
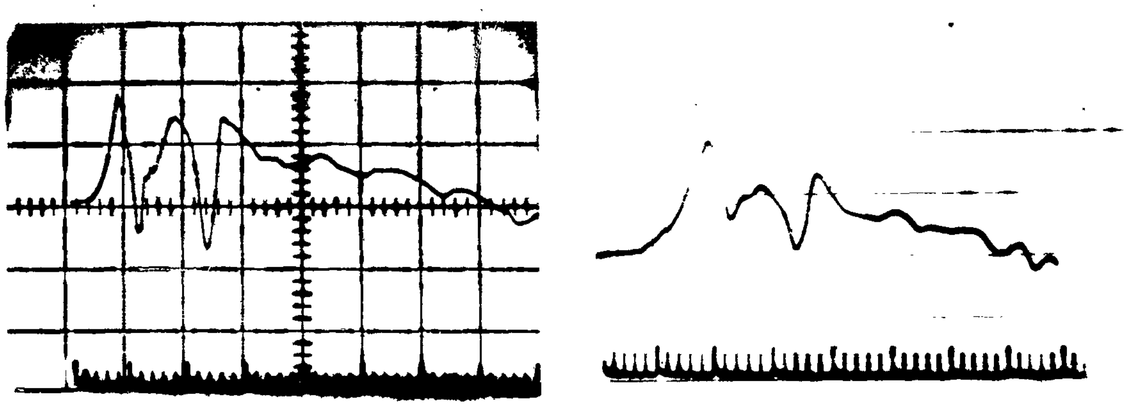


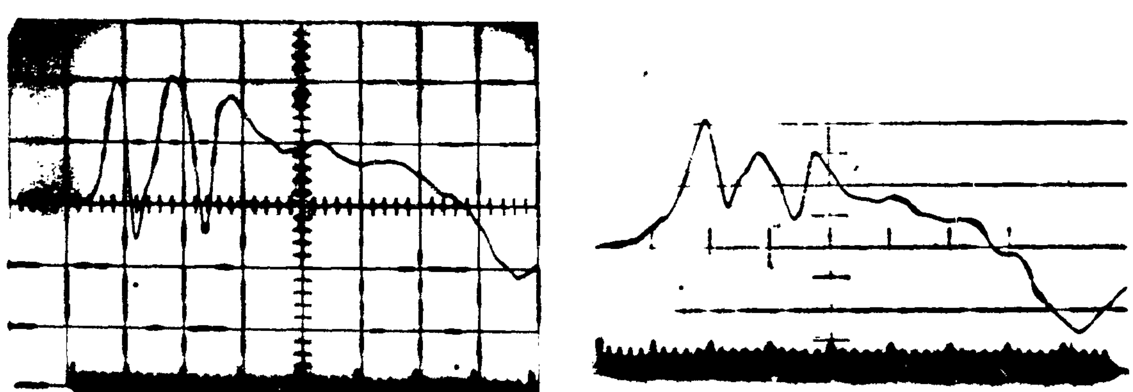
MAGNETIZING YOKE
FIGURE 1



3000 GAUSS INITIAL INDUCTION



7500 GAUSS INITIAL INDUCTION



10.8 CM 22.8 CM

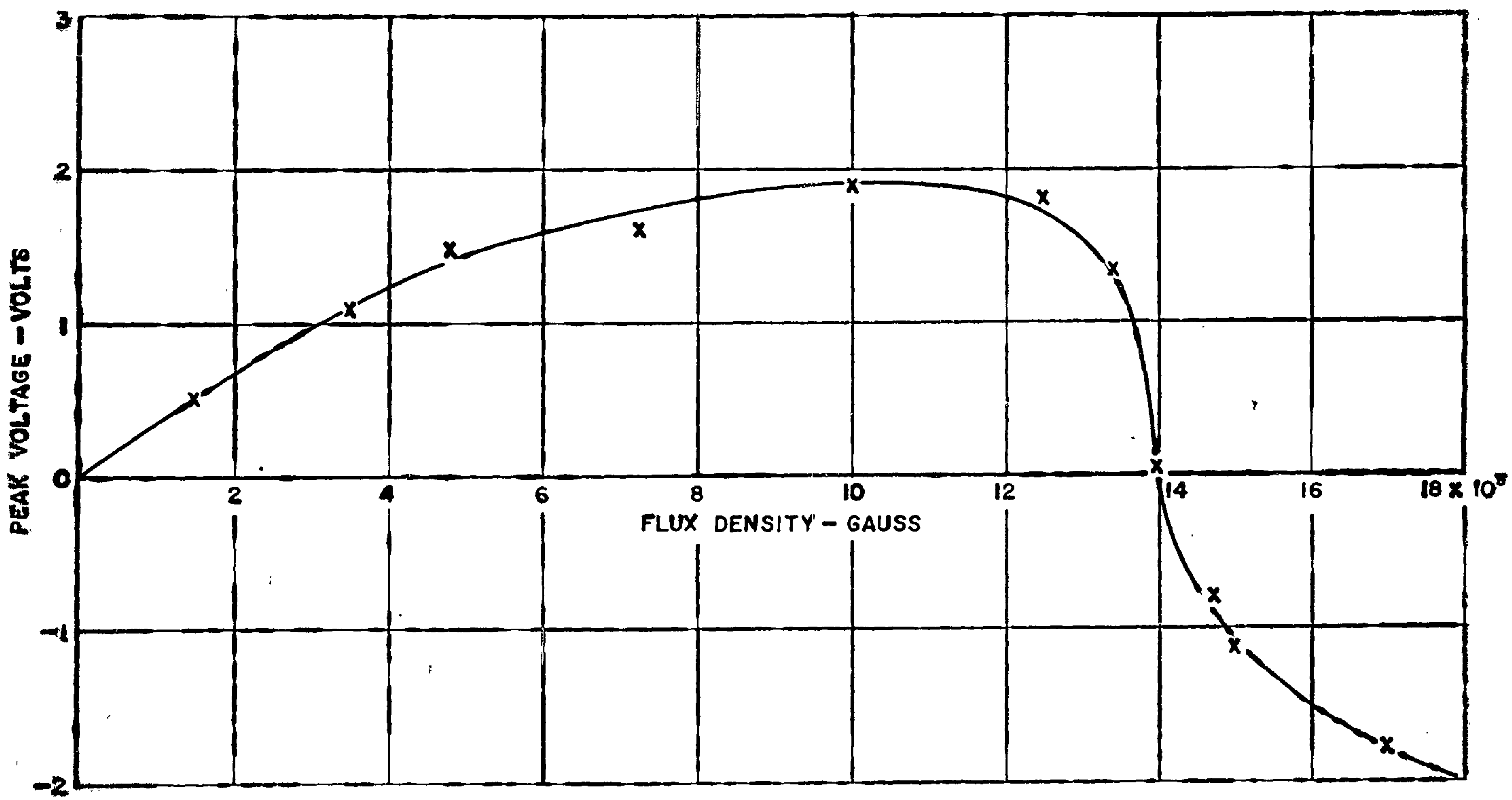
I VOLT/CM I MICROSECOND MARKERS

9000 GAUSS INITIAL INDUCTION

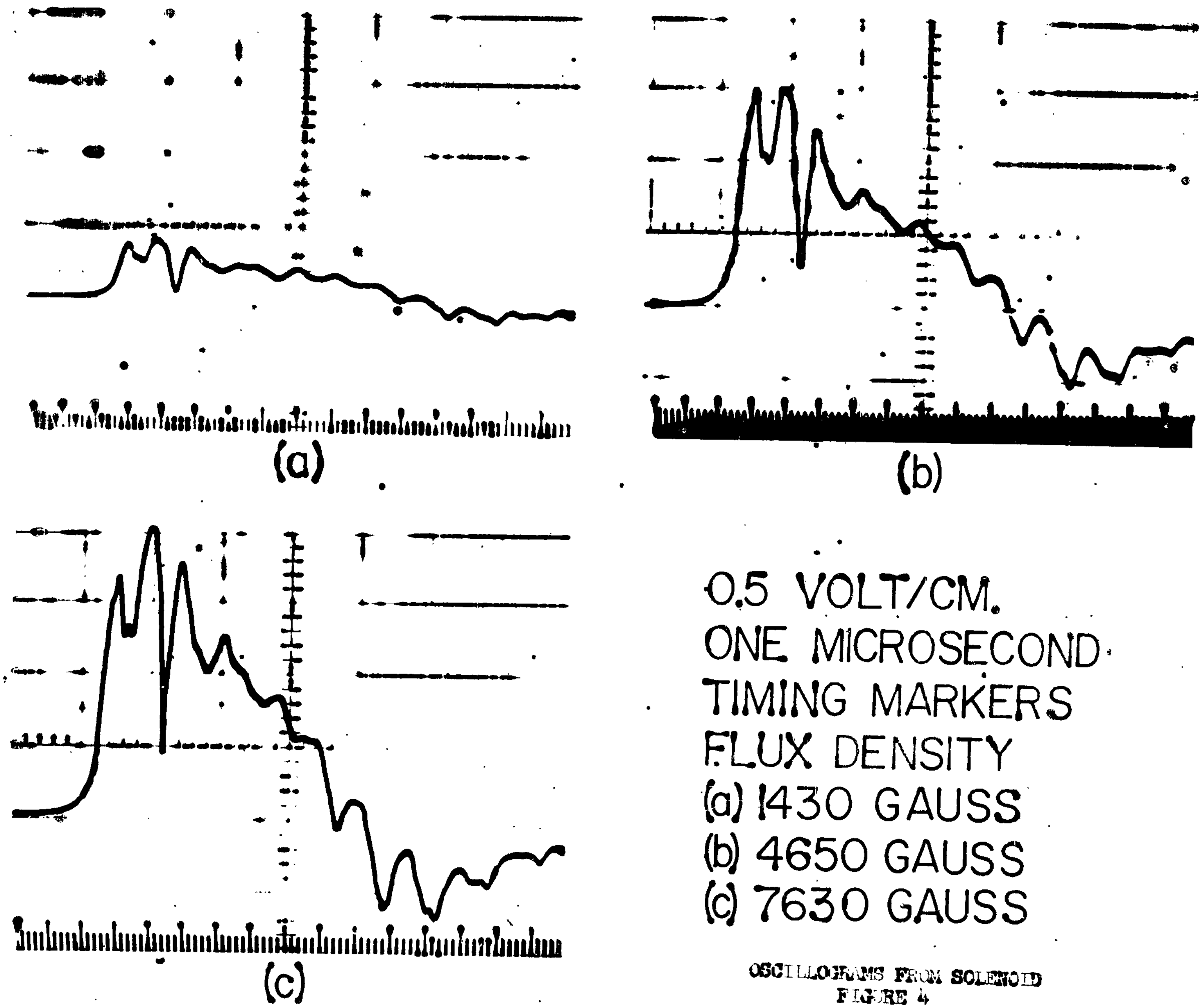
TYPICAL OSCILLOGRAMS

FIGURE 2

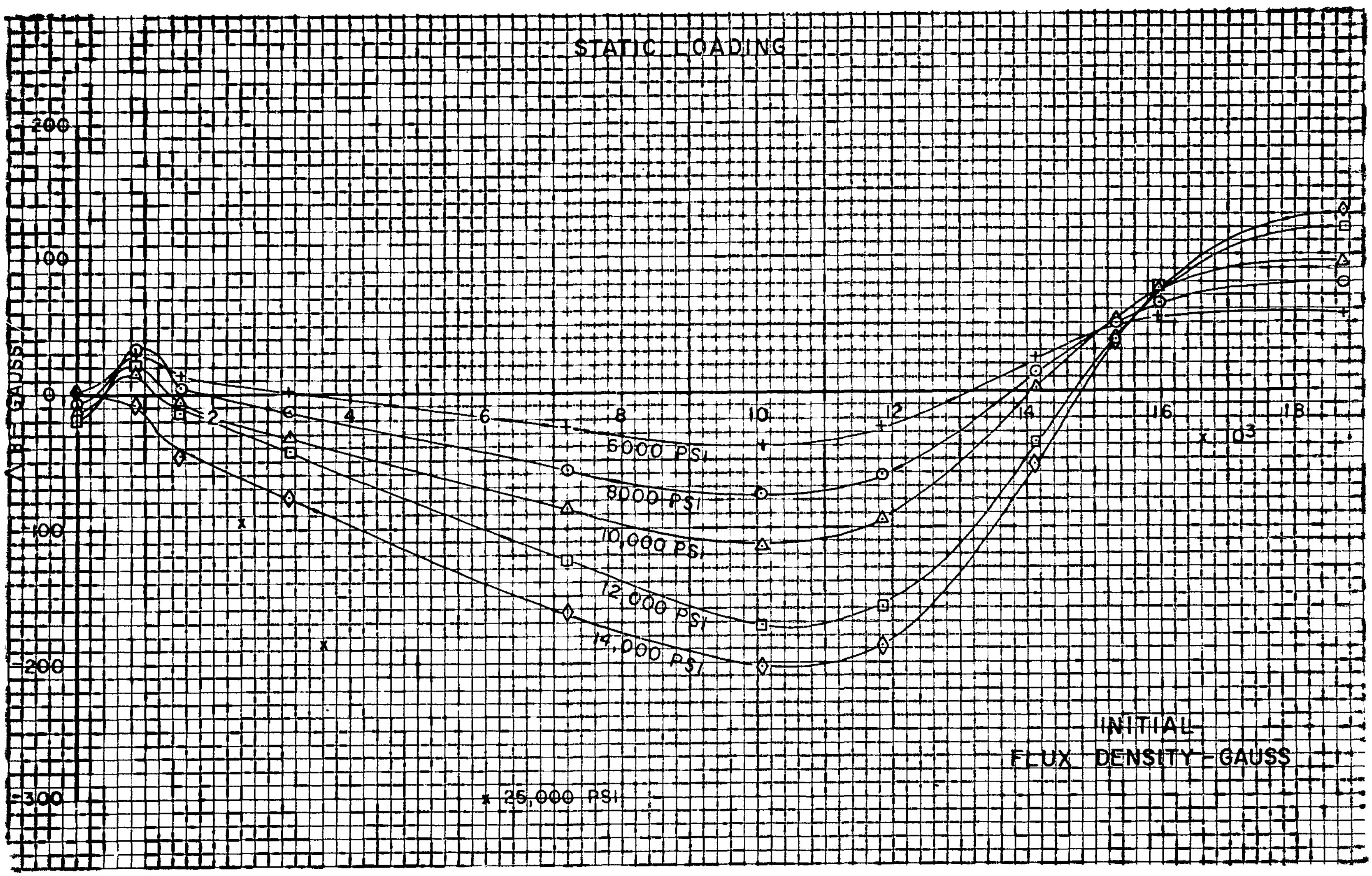
EXPLOSIVE LOADING



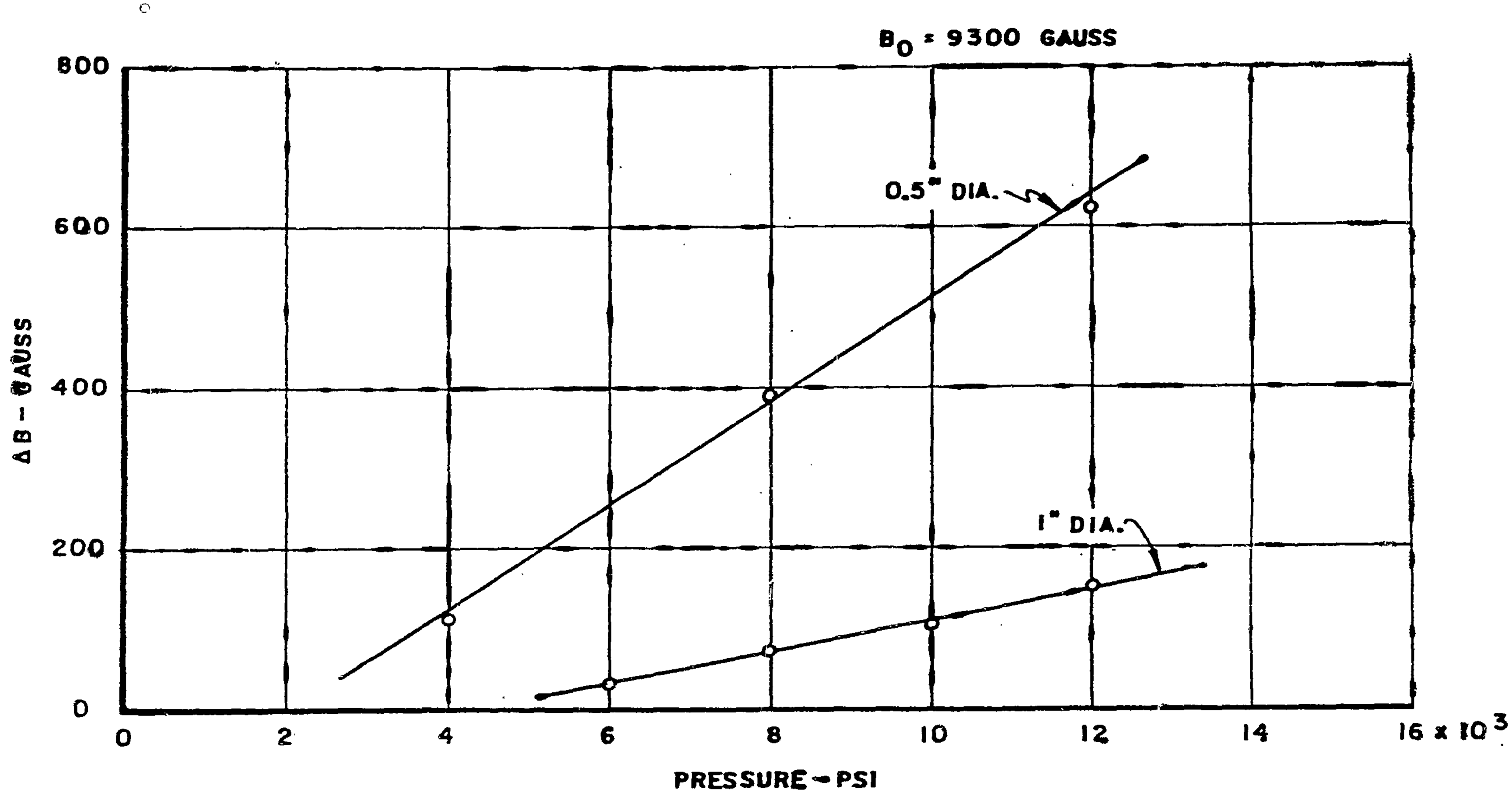
FIRST VOLTAGE PEAK VS. INITIAL INDUCTION
FIGURE 3



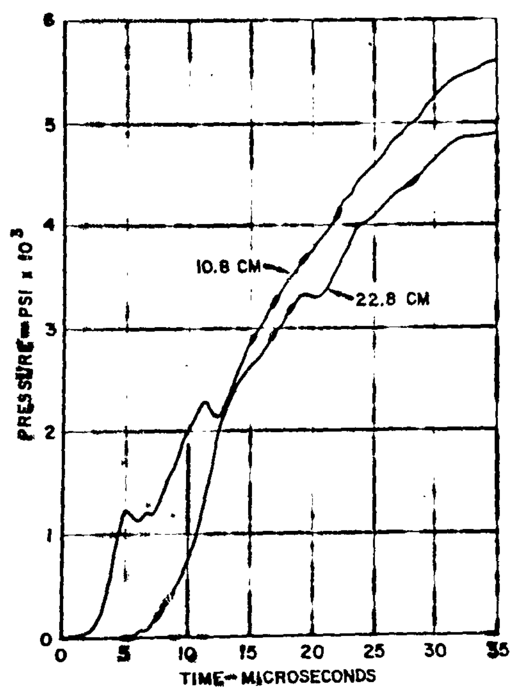
OSCILLOGRAMS FROM SOLENOID
FIGURE 4



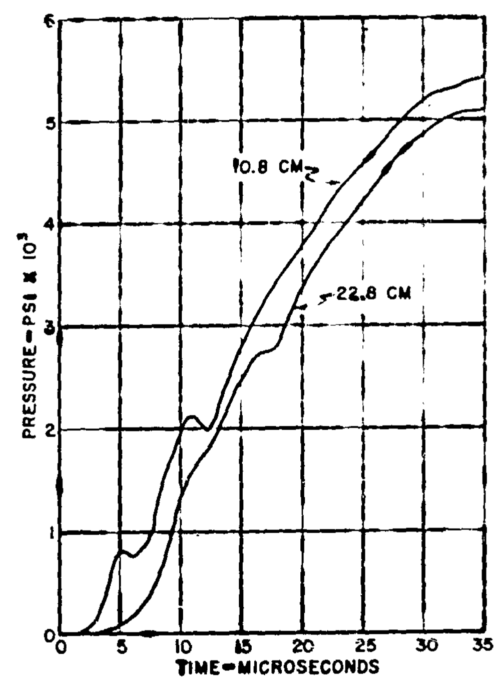
CHANGE IN INDUCTION VS. CHANGE IN PRESSURE
FIGURE 5



CHANGE IN INDUCTION VS. CHANGE IN PRESSURE
FIGURE 6



3000 GAUSS



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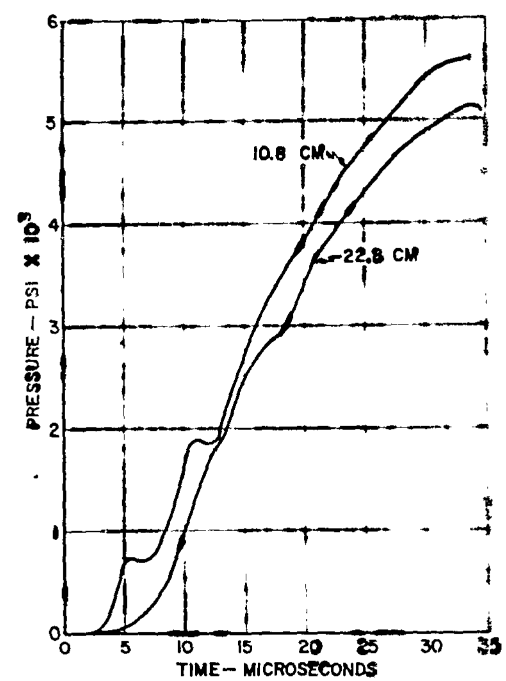
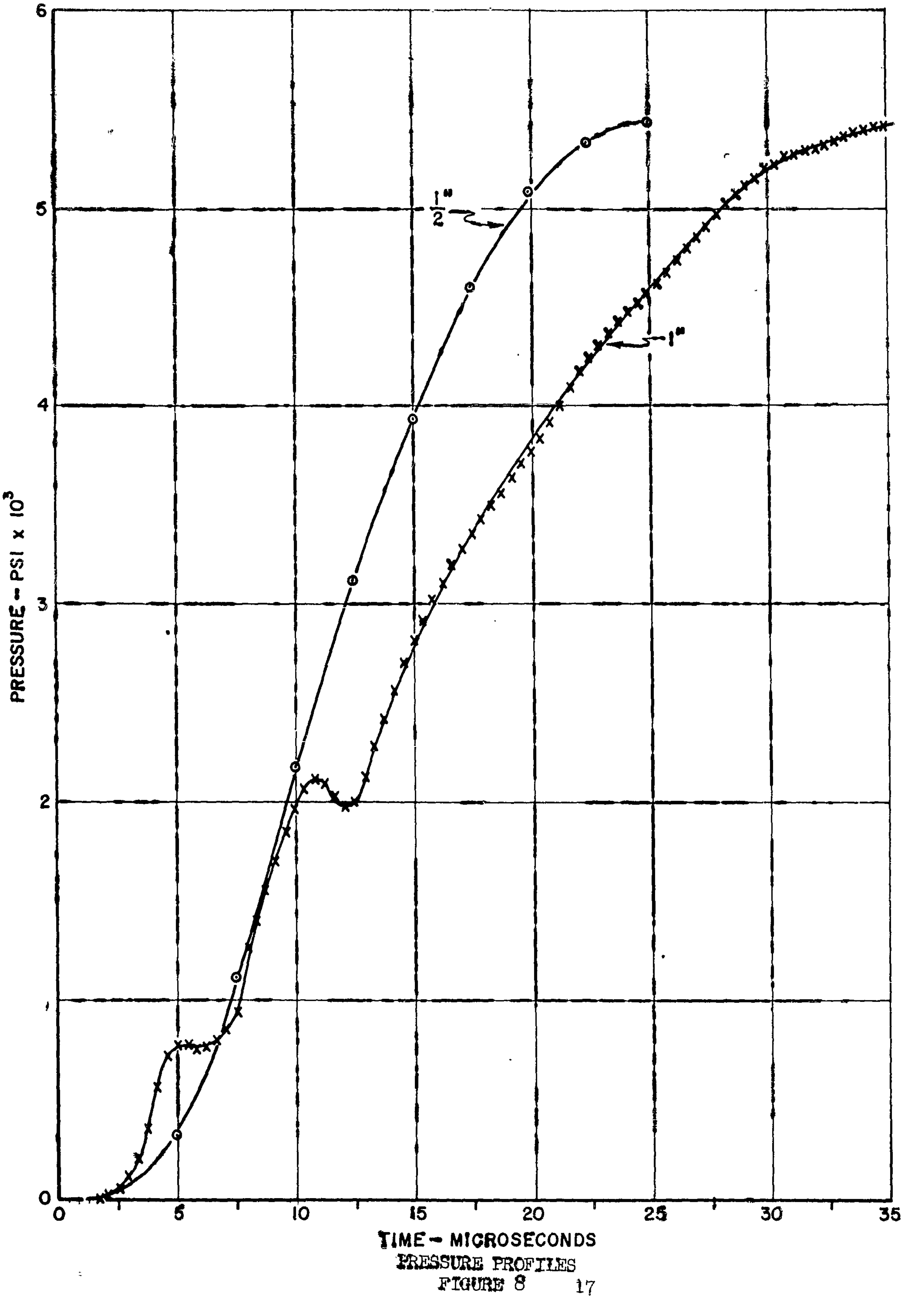


9000 GAUSS

PRESSURE PROFILES

FIGURE 7



PRESSURE PROFILES
FIGURE 8

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Pressure waves - Magnetic effects
Explosions - Physical effects
Steel - Magnetic properties

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